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ATMOSPHERIC AND STABILITY EFFECTS ON AERIALLY APPLIED AGRICULTURAL SPRAYS – PRELIMINARY RESULTS

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Abstract. *Drift from aerial application of crop protection materials is influenced by many factors such as mean wind, temperature, relative humidity, and atmospheric stability. The applicator is responsible for making all possible efforts to reduce drift. Atmospheric conditions and stability must be considered and adjusted for on the basis of real-time observations and past experience. The objective of this research was to further document the effects of atmospheric conditions and stability on the deposition, drift, and deposited droplet size characteristics of aerial sprays. Twelve replications using a fine aerial spray treatment were conducted over the course of a day. Ground deposition and airborne concentrations at multiple heights were collected at multiple downwind locations using mylar cards and nylon screen cylinders, respectively. Preliminary results indicated that wind speed was more dominant than stability, and increased wind speed resulted in increased downwind ground deposition, suspended concentrations, and transport of larger droplets downwind.*

Keywords. Aerial Application, aerial spraying, spray deposition, spray drift

INTRODUCTION

Aerially applied spray droplet transport is a function of atmospheric dispersion which is accomplished through means of gravitational settling, downwind transport by mean winds, aircraft wake turbulence, and turbulent mixing. The overall physical concepts of gaseous dispersion and the roles of atmospheric turbulence and stability play are well studied and documented. The impact of atmospheric stability on the transport and fate of agricultural sprays has not been well documented. Agricultural aerially applied sprays typically target droplet spectra composed of large diameter droplets (100 to 300 µm; for example) with minimal smaller "driftable" droplets (< 100 µm). While spray droplets less than about 50 µm have very low settling velocities and have similar transport characteristics as gaseous dispersion (Thistle, 2000), the larger spray droplet behavior has not been well documented.

The effects of stable atmospheric conditions are of most interest due to lowest atmospheric mixing characteristics the potentially lead to the greatest downwind transport, are the most difficult to address with full scale field studies due to their fleeting, variable nature and narrower plumes. Prediction of spray movement for downwind sampler placement as well as challenges associated with sampling airborne droplets adds to the complexity of planning and executing field studies. Several previous studies indicated that a more stable atmosphere increases the potential for drift of agricultural sprays (Yates et al., 1966; Yates et al., 1967; Miller et al. 2000; Bird, 1995; and Bird et al., 1996, Fritz, 2006) and this study aims to add to this body of work, to demonstrate a method for measuring airborne and ground deposited spray concentrations and droplet sizes at multiple downwind locations and heights, and to increase the level of knowledge in this area.

Effects of Atmospheric Stability on Aerially Applied Sprays

As mentioned earlier, several studies addressed the issue of atmospheric stability effects on aerially applied sprays. Yates et al. (1966 and 1967) observed decreases in downwind deposition with decreases in stability (very stable to unstable atmosphere). Yates et al. (1974) found that the effects of stability were greater at greater downwind distances. Miller et al. (2000) in reviewing the work by Yates et al. (1967) summarizes that their work found that wind speed dominates deposition in the near field (downwind distances where larger droplets are deposited by gravitational forces) while stability is more important in the far field (downwind distance where smaller droplets deposit by diffusion). This does not imply wind speed is not important in far field as the mean wind defines transport distance, while stability affects degree of mixing. Miller et al. (2000) found increased drift and deposition from evening airblast orchard applications under stable conditions compared to unstable conditions. MacCollom et al. (1986) observed greater drift distances and amounts under temperature inversions than in the absence thereof. Hoffmann and Salyani (1996) reported that downwind ground depositions were higher for nighttime application versus daytime application, and given that the most stable atmospheric conditions occur at nighttime (Pasquill, 1961), the results reported by Hoffman and Salyani (1996) supported previous findings.

Bird (1995) showed that the highest drift deposits among a compiled database of previous field studies were from tests with relatively high wind speeds coupled with a temperature inversion and small droplet spectra sprays. Bird et al. (1996) state that because extreme conditions of stability, for both stable and unstable conditions, are associated with light to calm winds, increased wind speeds will tend to lessen the extreme stability effects. Bird et al. (1996) further state that given similar stability conditions, increasing wind speeds will tend to increase off-target deposition (i.e. greater transport distance of suspended droplets), and that stability effects are most significant beyond 90 meters downwind. Previous work by the author found that atmospheric stability potentially increased entrainment residence time for smaller droplets sprays, but wind speed was a more dominant factor (Fritz, 2006). This previous study had limited data in the stable to very stable atmospheric range and lack multiple sampling heights for airborne concentrations, and downwind droplet sizing data. The study described herein was designed to address these issues.

Objectives

The objective of this study was to examine the effects of meteorological conditions including atmospheric stability on the fate and transport of aerially applied sprays.

Materials and Methods

Twelve replicated aerial application trails were conducted. Details of application equipment setup, data collection protocol and meteorological data collection are discussed in the following sections.

Application Equipment Setup

An AirTractor AT-402B was used for all applications and was operated at 209 km/hr (130 mph) with an aircraft spray boom height of 2.4 m (8 ft) and a swath width of 15 m (50 ft) and a spray rate of 28 L/ha (3 gpa). The spray solution consisted of water, Trition X-100 surfactant at 0.1% v/v, and Caracid Brilliant Flavine FFN fluorescent dye at 15 g/ha (0.013 lb/acre). Boom setup was configured to produce a FINE droplet spectrum based on ASAE Standard S572 AUG99 Spray Nozzle Classification by Droplet Spectra (ASAE, 2000). Application parameters and nozzle setups were selected to generate desired droplet spectrums using USDA-ARS Aerial Spray Nozzle Models (available for download at http://apmru.usda.gov/downloads/downloads.htm). Twenty-five CP-03 (CP Products, Inc., Mesa, AZ) nozzles were configured with the 3.175 mm (0.125 in) orifice and a 90° deflection angle, and were operated at 207 kPa (30 psi). This configuration resulted in a theoretical VMD (volume median diameter, DV0.5, is the diameter of droplet such that 50% of the total volume of droplets is in droplets of smaller diameter) of 236 μm; a V<200μm (Percent of spray volume contained in droplets less than 200 μm) of 34%; and a V<100μm (Percent of spray volume contained in droplets less than 100 μm) of 14%.

Meteorological Monitoring

Meteorological data were monitored throughout the tests using a meteorological tower. The tower was located approximately 100 meters downwind of the flight line directly alongside the sampling line. The meteorological tower measured one-minute averages of wind speed and direction (RM Young model 05701 Wind Monitor-RE), and temperature (RM Young model 43347VC Temperature Probes in a model 43408 aspirated radiation shield that were match calibrated with relative difference accuracy of 0.02 °C) at 2.5, 5, and 10 meters. Relative humidity was measured with an RM Young model 71372 temperature/relative humidity sensor. Stability ratio was calculated from tower data and stability class was defined based on stability ratio ranges set by Yates et al. (1974), as shown in Table 1.

Table 1. Atmospheric Stability Conditions as a Function of Stability Ratio Ranges. (Modified from Yates et al; 1974)

Atmospheric Stability Condition	Stability Ratio Range
Unstable	-1.7 to -0.1
Neutral	-0.1 to 0.1
Stable	0.1 to 1.2
Very Stable	1.2 to 4.9

Study Layout

The flight line and downwind sampling location were located in the center of a large field of wheat stubble. Three sub-samples of mylar collectors (A, B, and C) at multiple downwind distances were used to capture ground deposition of spray (Figure 1). The mylar cards (100 cm^2) were placed on square metal plates positioned flat on the ground. Monofilament nylon screen cylinders at multiple heights and locations on sampling towers collected the airborne portion of the spray (Figure 1). Sampling heights of 0.3, 3, and 6 m were selected in an effort to characterize the spray plume (Figure 1). Additionally, water sensitive papers (WSP) were place flat on the ground at various downwind locations as well as at 0.3 and 6 m height on the sampling towers, oriented vertically facing into the wind (Figure 1).

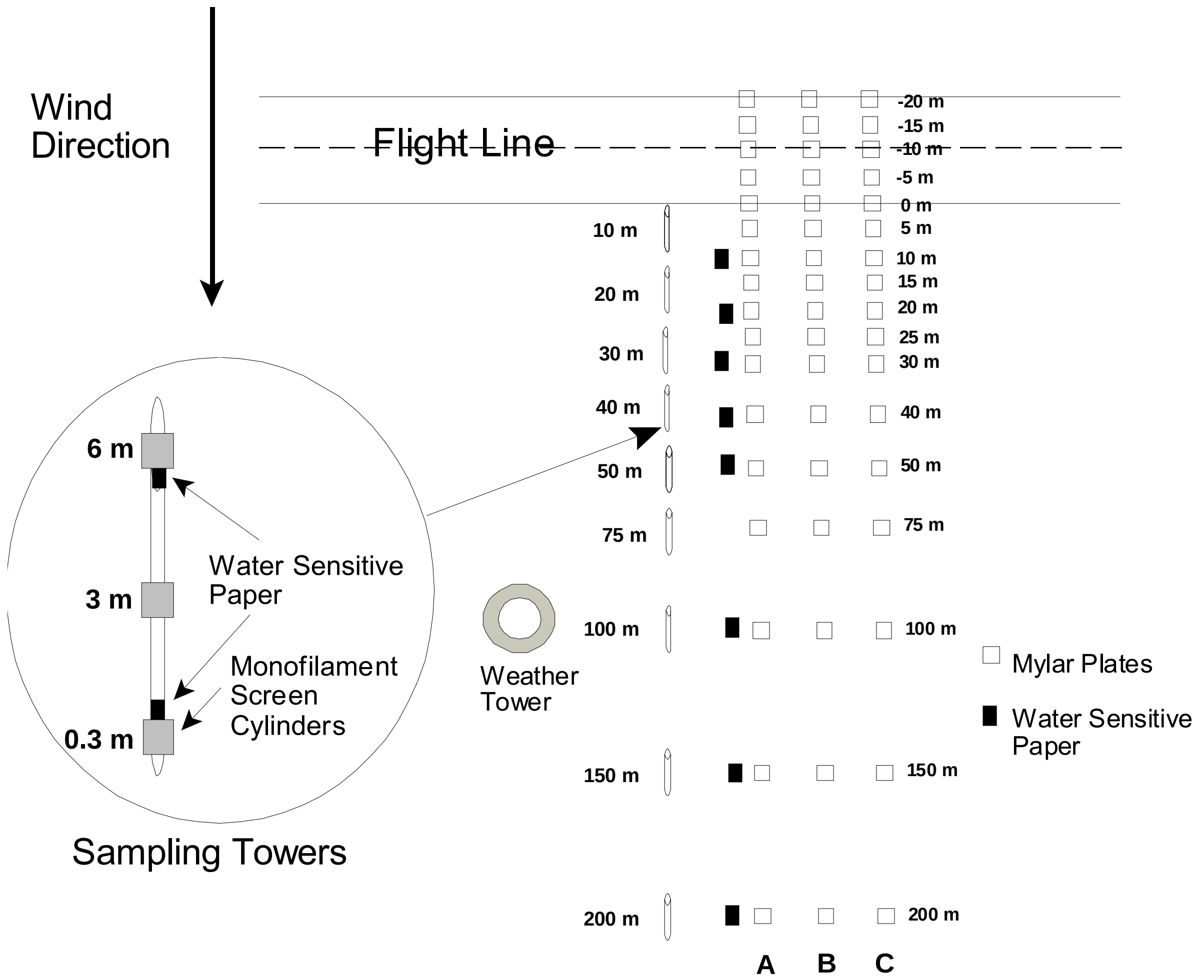

Figure 1. Test layout for field studies.

Replications 1 through 6 were completed in the morning as soon as the pilot was safe to fly and replications 7 through 12 were completed prior to darkness. The aircraft made two passes, one with the left wing on the downwind side and another with the right wing on the downwind side. Spray was activated 300 m before the sampling line and deactivated 300 m after the sampling line.

Sample Collection and Processing

Following each replication, five minutes were allowed for spray material to travel downwind prior to collection of all sampling media. Mylar cards and nylon screen cylinders were collected and immediately place in labeled plastic bags, which were then placed and sealed in an ice chest for transport to the laboratory. Analysis consisted of pipetting 20 - 40 ml of an ethanol wash into each bag, agitating the sample bag, and decanting 6 ml into a cuvette. The dye concentration (µg/ml) of samples and tank mixture were measured using a spectrofluorometer (Shimadzu, Model RF5000U, Kyoto, Japan) and reference standards. The sample concentration was multiplied by the wash volume and divided by the effective sample area to get µg of dye/cm^2.

WSP samples were processed with computerized image analysis (IMAQ Vision Builder v5, National Instruments, Austin, Texas) to determine droplet stain density and stain size. Stain size, stain diameter, and minimum stain dimension were determined in two 0.75 cm^2 sample areas on each card. Each stain in the sample area was converted to droplet diameter with an experimentally determined spread factor (0.54*stain diameter – $8.5x10^{-5}$*stain $diameter^2$, developed experimentally in-house).

Data Analysis

Mylar and nylon screen deposition data were corrected for wind direction by adjusting the source strength using a line source projection (Thistle, 2005). The wind direction corrected mylar and monofilament string data were analyzed using regression analysis with SAS (2001) PROC MIXED. Variation among the mylar sub-samples within each replication were accounted for using spatial autocorrelation. The analysis also accounted for the unequal variances as a result of unequal sample sizes between atmospheric stability conditions using SAS data set groupings. Additional regression analysis using SAS (2001) PROC MIXED examined the effects of meteorological parameters on mylar and nylon screen cylinder deposition. All significance testing was done at the α = 0.05 level unless otherwise noted in text.

Results

Meteorological Data

Data recorded for each test are presented in Table 2. The data represents averaged data corresponding to a five minute period starting when the aircraft initiated spraying.

Table 2. Meteorological data measured and calculated for each test replication.

Rep	Time of Acquisition	Temp. at 10 m (°C)	Temp. at 2.5 m (°C)	Relative Humidity (%)	Wind Speed at 5 m (m/s)	Stability Ratio	Yates et al. (1976) Stability Class[1]	Wind Direction at 5 m	Theta[2]
1	7:16 am	22.0	21.5	95.7	0.5	21.2	VS	207.5	-27.5
2	7:43 am	22.8	23.0	92.1	0.5	-9.1	U	112.8	67.2
3	8:02 am	23.9	24.2	88.7	1.0	-3.4	U	125.3	54.7
4	8:18 am	24.6	24.8	86.2	0.8	-3.9	U	134.5	45.5
5	8:35 am	25.5	25.8	82.7	1.0	-4.0	U	156.6	23.4
6	8:50 am	26.2	26.6	79.0	0.9	-5.8	U	162.5	17.5
7	7:04 pm	34.3	34.5	37.8	2.5	-0.2	U	126.1	53.9
8	7:20 pm	34.2	34.1	38.7	2.5	0.1	S	124.9	55.1
9	7:36 pm	33.8	33.5	42.1	2.2	0.6	S	138.6	41.4
10	7:52 pm	33.7	33.3	42.2	2.4	0.7	S	178.2	1.8
11	8:08 pm	33.1	32.6	44.5	2.4	0.9	S	171.5	8.5
12	8:24 pm	32.4	31.4	48.3	1.6	3.7	VS	172.7	7.3

[1] VS - Very Stable, S – Stable, U - Unstable

[2] Theta equals 180 minus the wind direction at 5 m. It is the value used for the projected line source correction on the mylar and nylon screen data.

Ground Deposition (Mylar Data)

Distance was a significant effect (α < 0.0001) while stability (α = 0.5834) and distance by stability interaction effects (α =0.1112) were not significant. Further analysis examined wind speed effects by dividing the mylar deposition data into two wind speed groups; A (< 2 m/s) and B (> 2 m/s). The wind speed grouping effect was significant (α = 0.0255) and wind speed group mean square deposition differences were significant at 10 m (α < 0.0001) and 15 m (α = 0.0028). Figure 2 is a plot of the least square mean estimates for wind speed group by downwind distance.

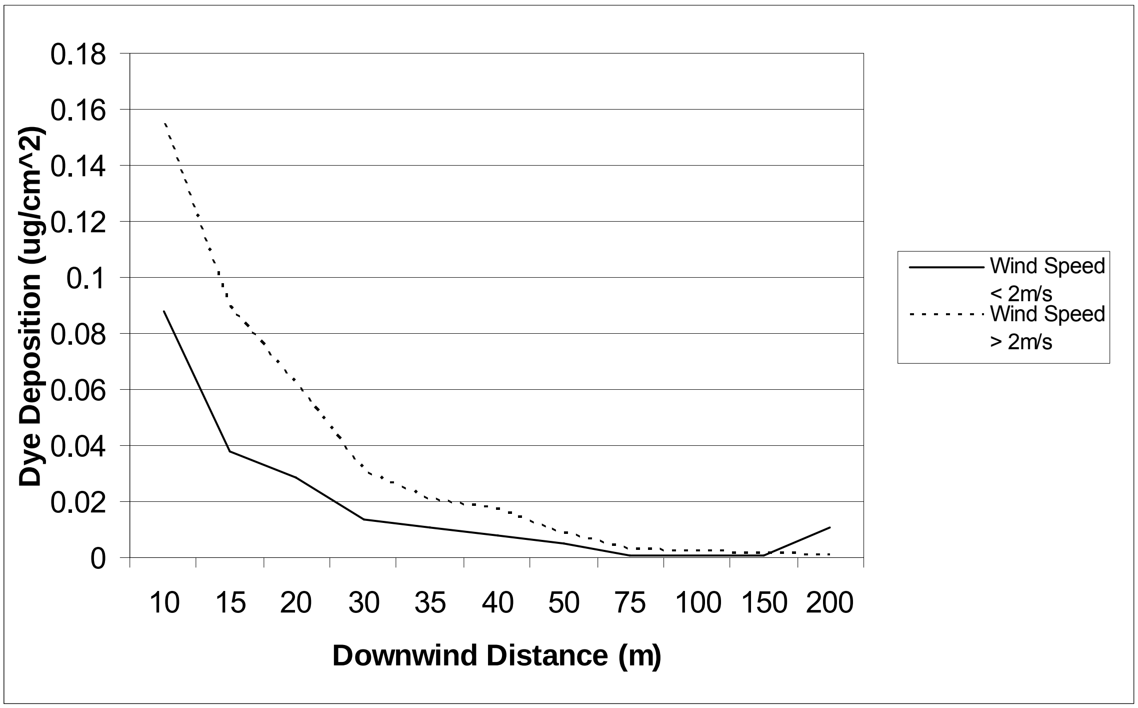

Figure 2. Least square mean deposition by wind speed group for mylar samples.

Airborne Concentration (Monofilament Screen Data)

Sampling screens at 0.3 m elevations

Distance (α <0.0001), distance by stability class interaction (α < 0.0001) and wind speed (α = 0.0065) where all significant while stability class (α = 0.6709) was not. A wind speed grouping and analysis, similar to that done on the mylar data, was performed. Wind speed groupings were the same as for the mylar. Wind speed group (α = 0.0027), distance (α < 0.0001) and wind speed group by distance (α = 0.0002) effects were all significant. Overall, higher wind speeds (group B) resulted in more than ten times the overall downwind screen measured concentration than that from low wind speeds (group A). Figure 3 is a plot of least square mean estimates of screen concentrations at 0.3 m by wind speed group and downwind distance. Least square mean concentration differences between wind speed groups were significant out to 30 m.

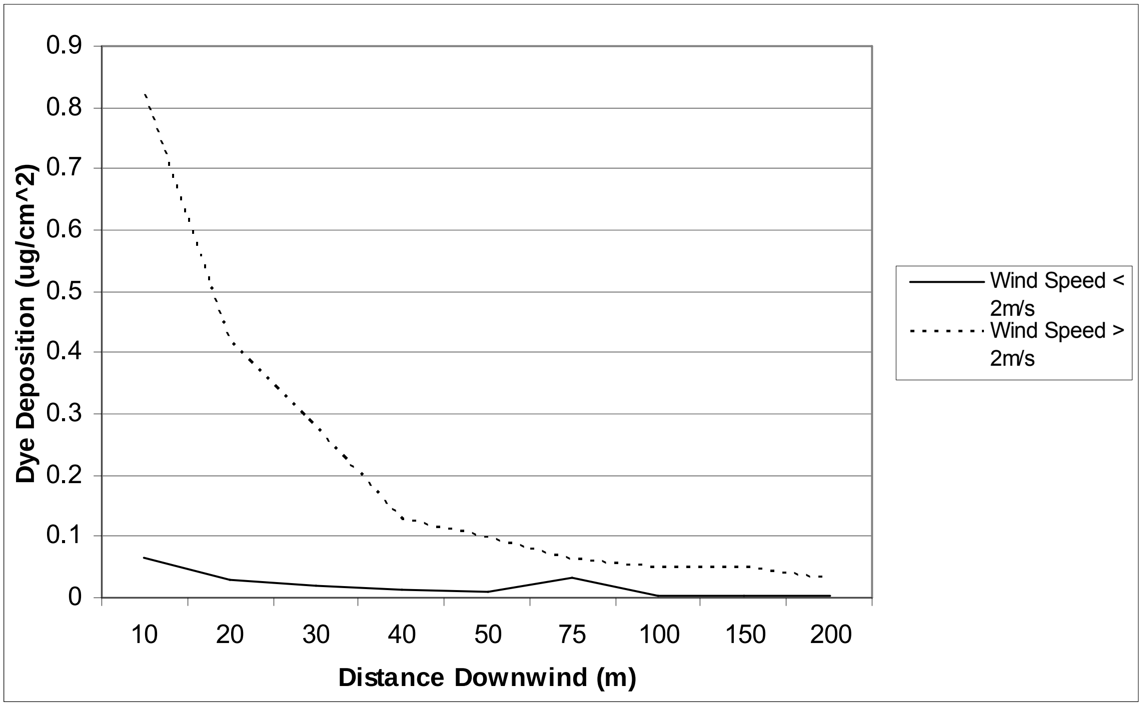

Figure 3. Least square mean concentration by downwind distance and wind speed group for nylon screen samples at 0.3 m elevation.

Sampling screens at 3 m elevations

Distance (α <0.0001), distance by stability class interaction (α < 0.0001) and relative humidity (α = 0.0019) where all significant while stability class (α = 0.6564) was not. Most of the unstable conditions occurred during the morning tests, which were also associated with lower temperature, and thus higher humidity, and more significantly, lower wind speeds than the afternoon tests where the majority of the stable conditions occurred. Examining the 3 m screen data by wind speed grouping, as mentioned previously, shows significant wind speed group effect (α < 0.0001). Overall, higher wind speeds (group B) resulted in almost eight times the total downwind screen concentration than that from lower wind speeds (group A). Least square mean concentration differences between group A and B were significant up to 40 m downwind. Figure 4 is a plot of least square mean screen concentrations at 3 m by wind speed group and downwind distance.

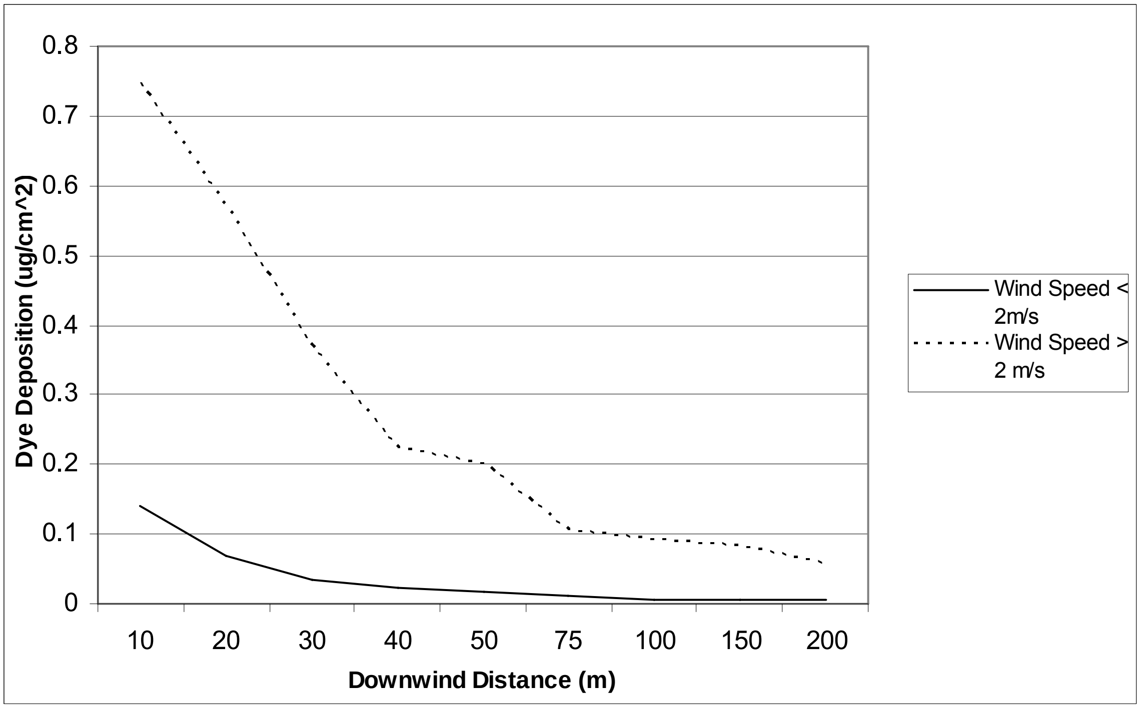

Figure 4. Least square mean concentration by downwind distance and wind speed group for nylon screen samples at 3 m elevation.

Sampling screens at 6.1 m elevations

Distance ($\alpha < 0.0235$) and relative humidity ($\alpha = 0.0011$) where the only significant parameters for the 6.1 m screen concentration data. Similar to the 3 m screen data, analysis with respect to wind speed grouping was also performed. Wind speed group ($\alpha < 0.0001$) was significant with higher wind speeds resulting in over six times the downwind screen concentration than that from lower wind speeds. Differences in least square mean concentration estimates between wind speed groups were significant up to 50 m downwind. Figure 5 is a plot of least square mean estimates of screen concentrations at 6.1 m by wind speed group and downwind distance.

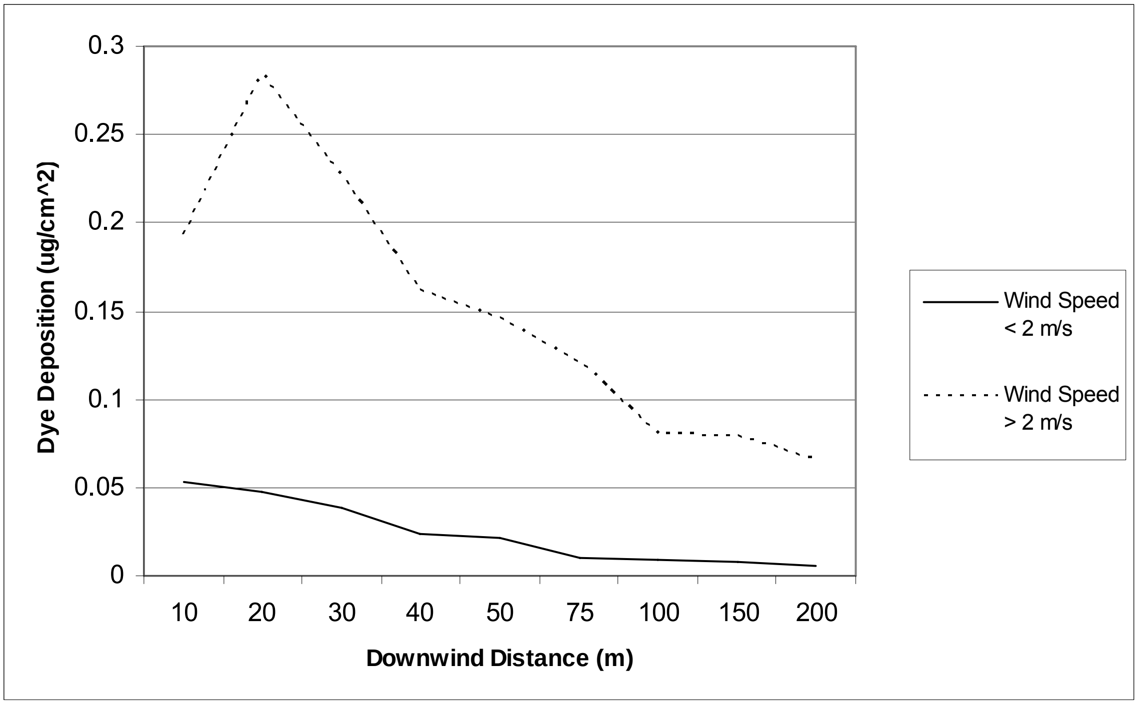

Figure 5. Least square mean concentration by downwind distance and wind speed group for nylon screen samples at 6.1 m elevation.

Water Sensitive Paper Droplet Size Data

Analysis of the WSP data showed no significant differences in droplet size between stability classes for the WSP placed flat on the ground, at the 0.3 or 6.1 m tower locations. Similar to the mylar and screen data sets, the WSP data was grouped and analyzed based on wind speed groupings (Group A – < 2 m/s; and Group B – > 2 m/s). Plots of mean VMD by wind speed group and downwind distance for ground, tower at 0.3 m, and tower at 6.1 m are given in Figure 6, 7 and 8. For the ground WSP, wind speed grouping was significant at the $\alpha = 0.10$ level ($\alpha = 0.0629$) with VMD least square means being significantly different at 10 m. For the WSP on the towers at 0.3 m, wind speed grouping was significant ($\alpha = 0.0240$) with VMD least square means being significantly different at 10 m. For WSP samples on the towers at 6.1 m, wind speed grouping was not significant ($\alpha = 0.1009$), but wind speed group by downwind distance was significant ($\alpha = 0.0396$) with VMD least squares means differing significantly (at $\alpha = 0.1$ level) at 50 m ($\alpha = 0.10$).

Note that results presented with respect to airborne and ground data indicated measurable concentrations out to 200 m while the WSP data shows VMDs around 20-30 μm, which is the smallest size detectable by the image analysis software used.

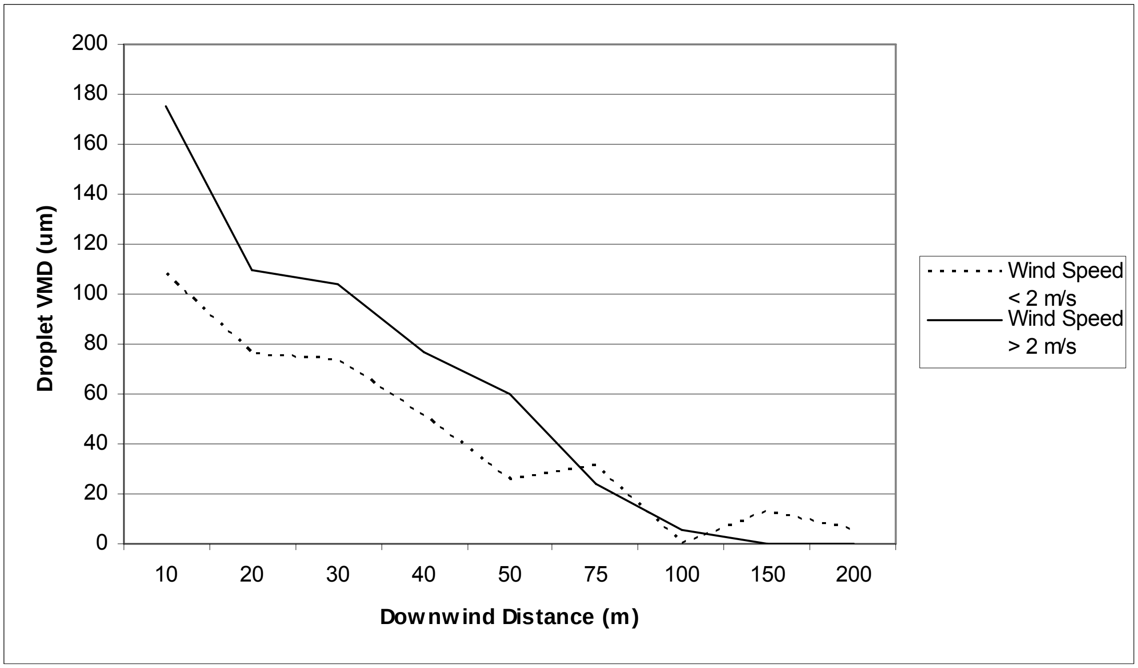

Figure 6. Mean droplet VMD by downwind distance and wind speed group from WSP samples placed horizontally on the ground.

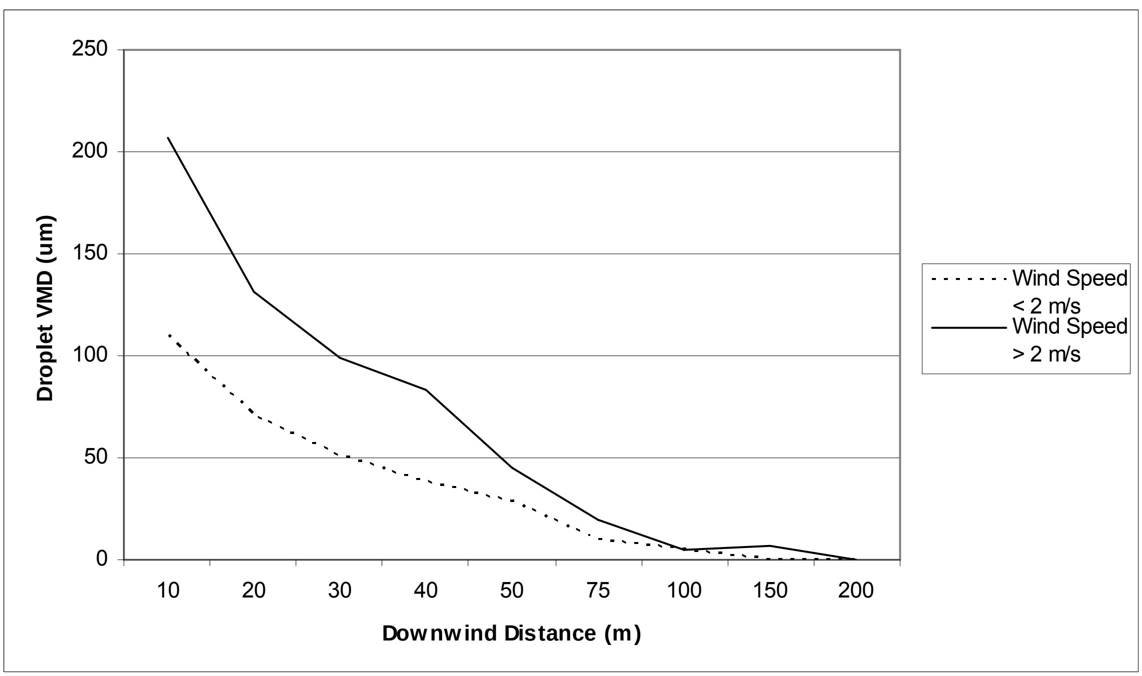

Figure 7. Mean droplet VMD by downwind distance and wind speed grouping from WSP samples placed vertically on tower at 0.3 m elevation.

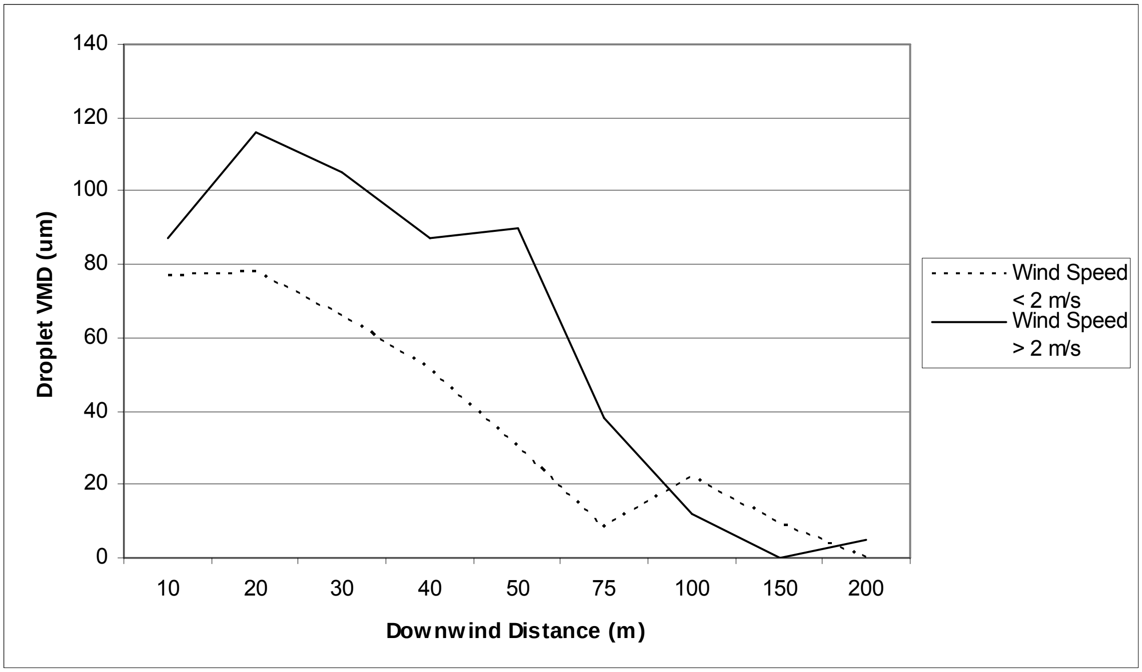

Figure 8. Mean droplet VMD by downwind distance and wind speed grouping from WSP samples placed vertically on tower at 6.1 m elevation.

Conclusions

This study was a continuation of field tests designed to quantify the behavior of sprays under various atmospheric conditions. A series of twelve replications were conducted over a field of wheat stubble where ground deposition and elevated (0.3, 3, and 6.1 m) airborne concentrations were measured with mylar plates and nylon screen cylinders, respectively, at multiple downwind distances.

Conclusions from this study were:

- No significant stability effects on ground deposition, airborne concentration, or droplet size distribution.
- Wind speed was significant with increased wind speed resulting in increased ground deposition, airborne concentrations, and deposited droplet size distribution.
- Higher wind speeds increased the travel distance of larger spray drops which increased deposition and suspended concentrations downwind.
- No significant effects from either stability or wind speed on deposition or suspended concentration past 75 m downwind.
- Evidence of suspended spray concentration at all elevations at and beyond the 200 m distance of spray consisting of droplets less than 20 to 30 μm.
- Wind speed is a more dominant factor than stability for the trials conducted for this work.

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